A Four-Plane proposal for Single-Phase LArTPC

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Overview

- Motivation of four wire plane for single-phase APA
  - Reduce ambiguities
  - More resistance to dead channels
  - Increase the acceptance for induction signal

How many planes do you need?

- LArTPC provides us three sources of information:
  - Time: When does a hit arrive?
  - Geometry: Which “wire” does a hit fire?
  - Charge: How large is a hit?

- The number of planes largely belongs to the geometry information
  - Intuitively, we know three planes are better

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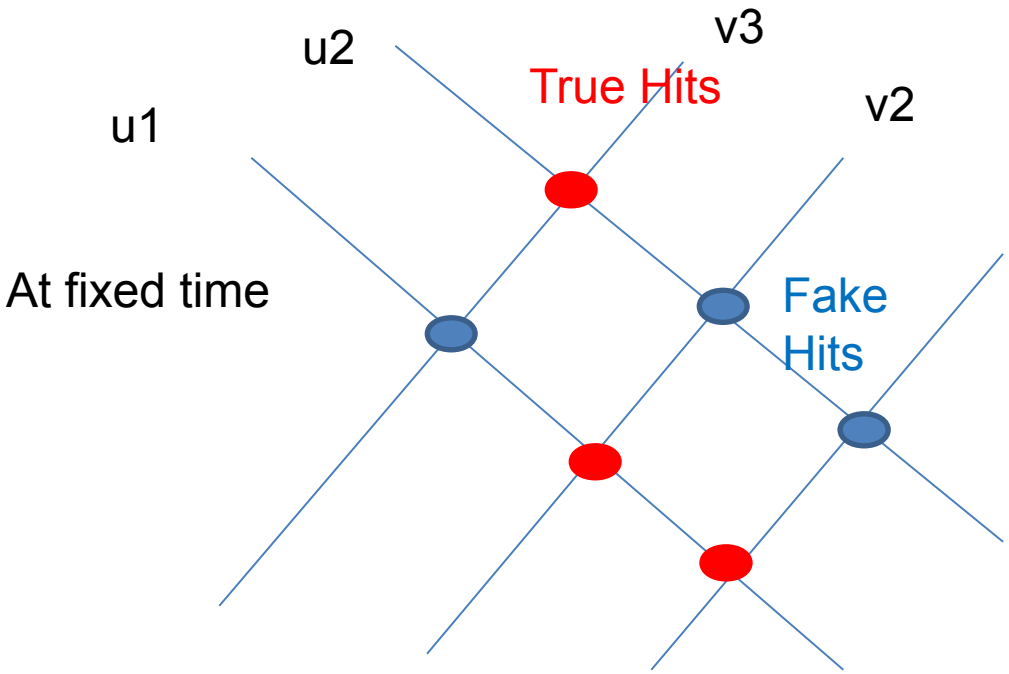
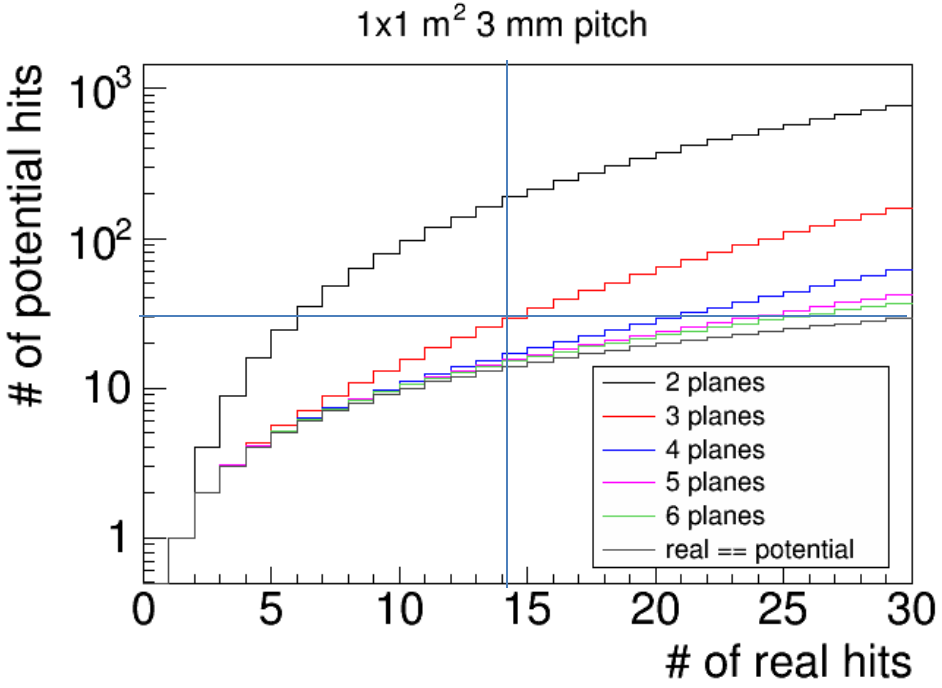
Real Hits vs. Potential Hits



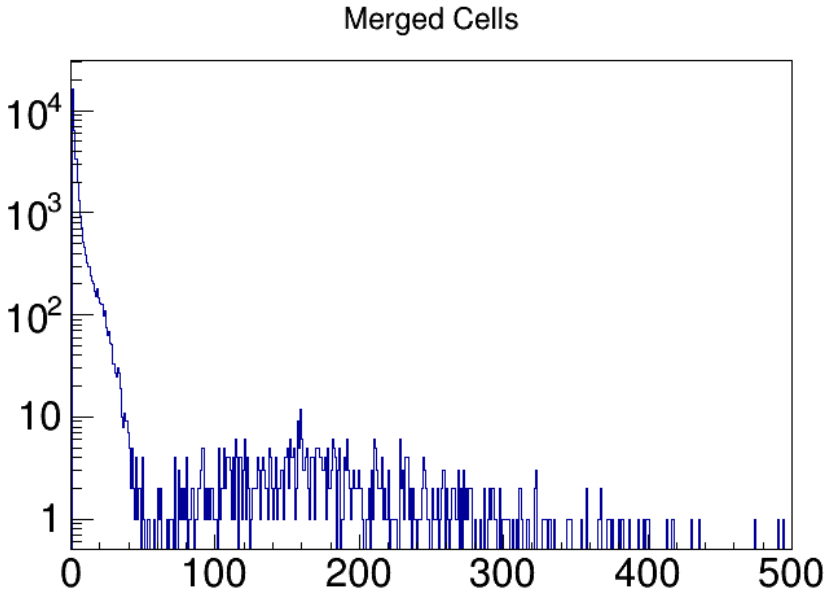
- Ambiguities can be evaluated by comparing the "# of real hits" and the "# of potential hits"
- Take two-plane as an example
  - 3 real hits
  - 6 potential hits (each has two fired wires going through them)

- Ambiguities can be reduced with Connectivity, Charge, Recognized Pattern information
  - These tools are powerful, but not yet robust enough
  - It is much desired to have less ambiguities to start with

Toy MC, evenly distributed wire angles



Toy MC, a hit only fire one wire in a plane



Number of potential hits for ve CC events in DUNE for the default configuration

- **Three-plane setting is much better than two-plane setting, the latter has two much ambiguities**
- **Four-plane setting can significantly reduce the ambiguities, especially when things are busy**

Consideration of Dead Channels

- In reality, it is highly unlikely to have 100% good channels for a 10 kt detector
  - Therefore, we need to take this into account in the design
- Let's assume "p" is the efficiency of a single plane, the given "n" number of planes, the volume efficiency can be estimated as

$$e_n = p^n$$

- The efficiency would be higher if $n-1$ planes are required

$$e_{n-1} = p^n + n(1-p)p^{n-1}$$

Considerations of Dead Channels

- For example, if we assume "p" = 90% and we have three planes, the three-plane efficiency will be around 73%, and the two-plane efficiency will be 97%
- However, the cost of higher efficiency is an increase of ambiguities (i.e. fake hits)
- We can thus estimate the fake hits as

$$\left(F_n + (1-p) \times n \times \left(F_{n-1} - F_n \right) \right) \times e_{n-1}$$

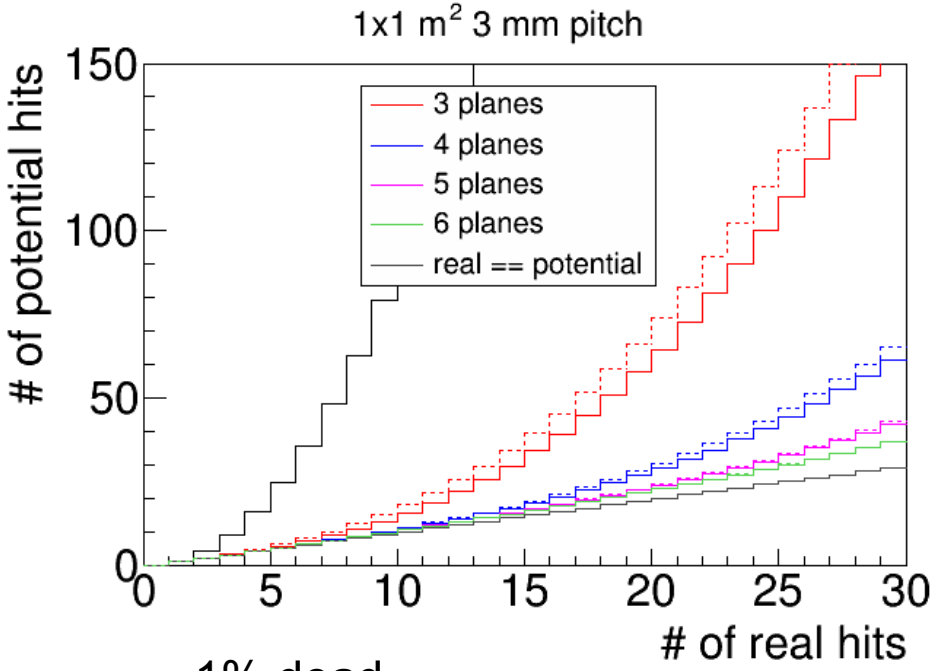
Original fake hits at "n" planes

Increase of fake hits due to dead channel, leaked from fake hits at "n-1" planes, n different "n-1" planes

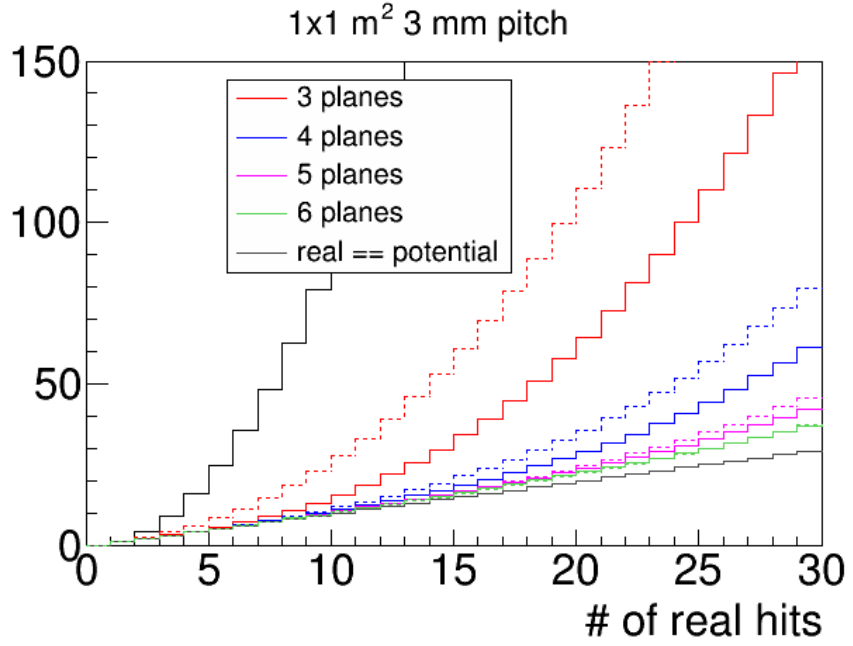
Overall reduction in efficiency

Let's take three cases: 1%, 5%, 10%

	1% (n/n-1)	5%	10%
3-plane	97% / 99.97%	85.7% / 99.2%	73% / 97%
4-plane	96% / 99.94%	81.5% / 98.6%	66% / 95%
5-plane	95% / 99.90%	77.4% / 97.7%	59% / 92%



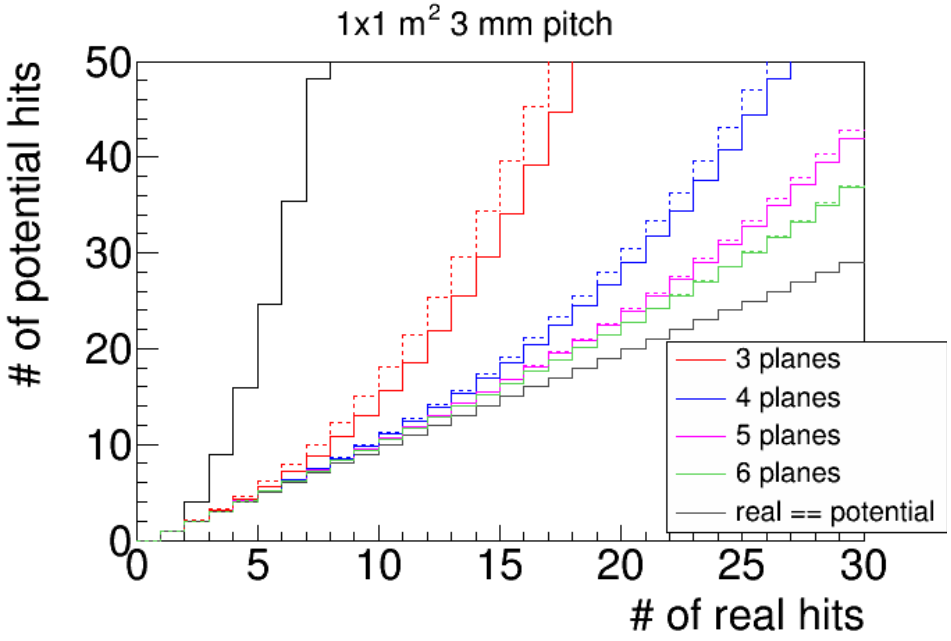
1% dead



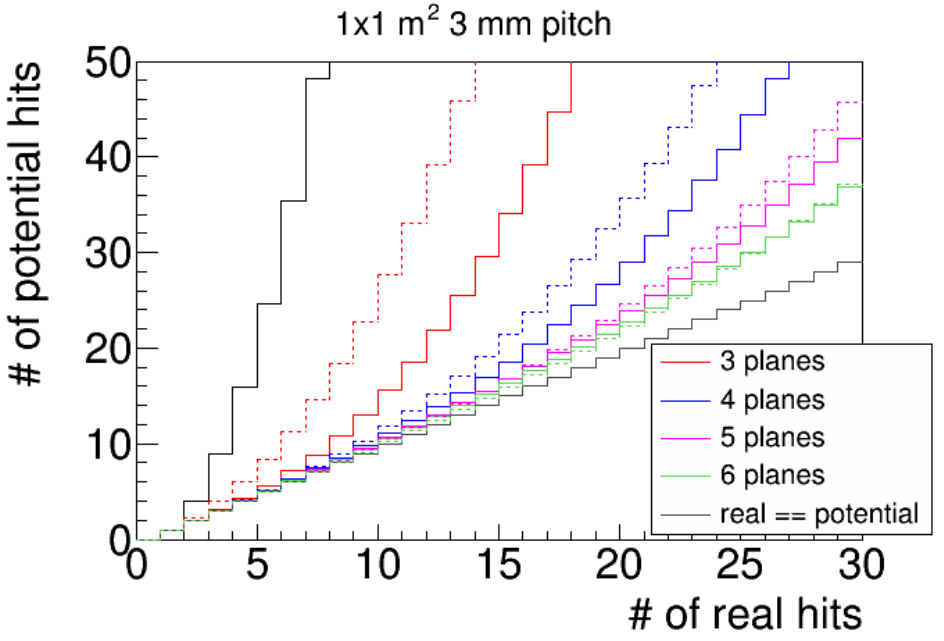
5% dead

Zoom-in View

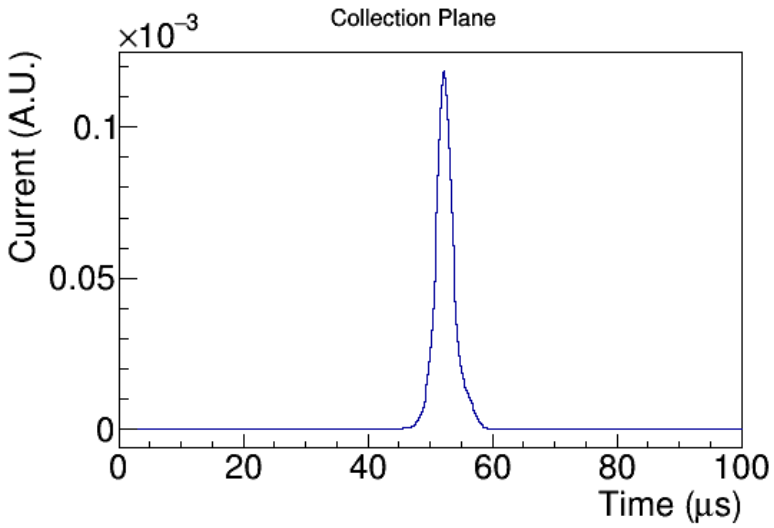
1% dead

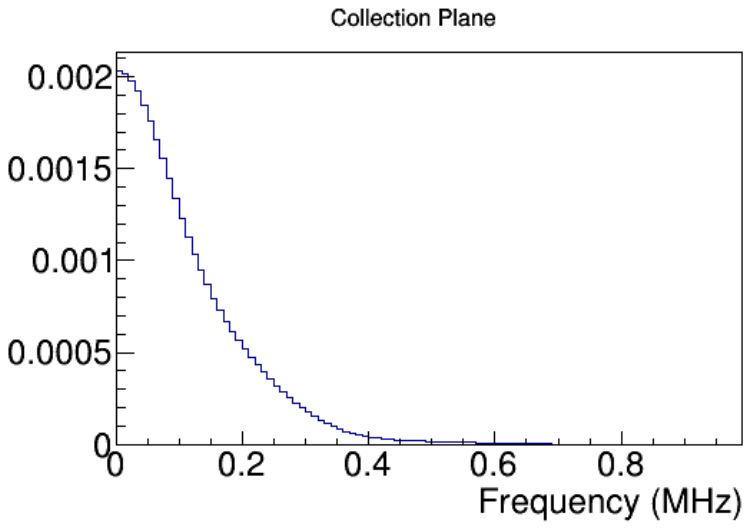


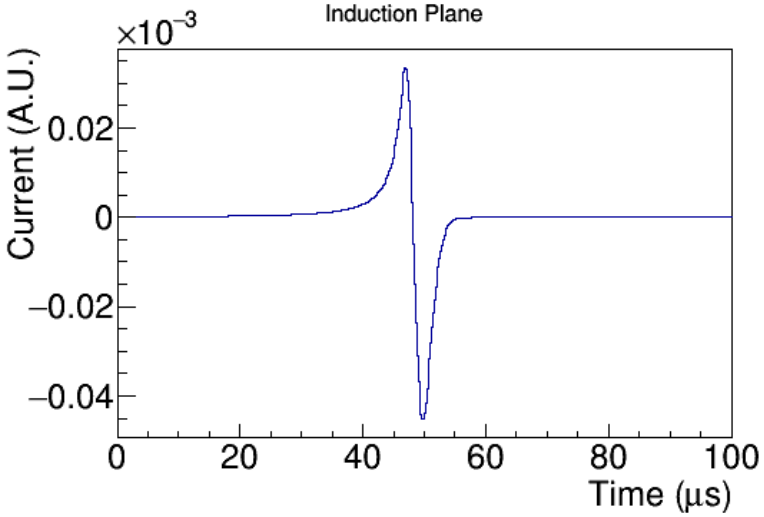
5% dead

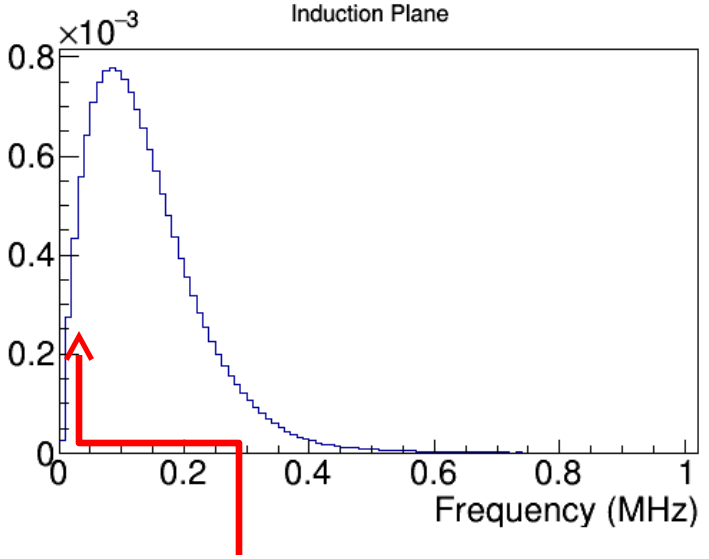


Collection vs. Induction Signal





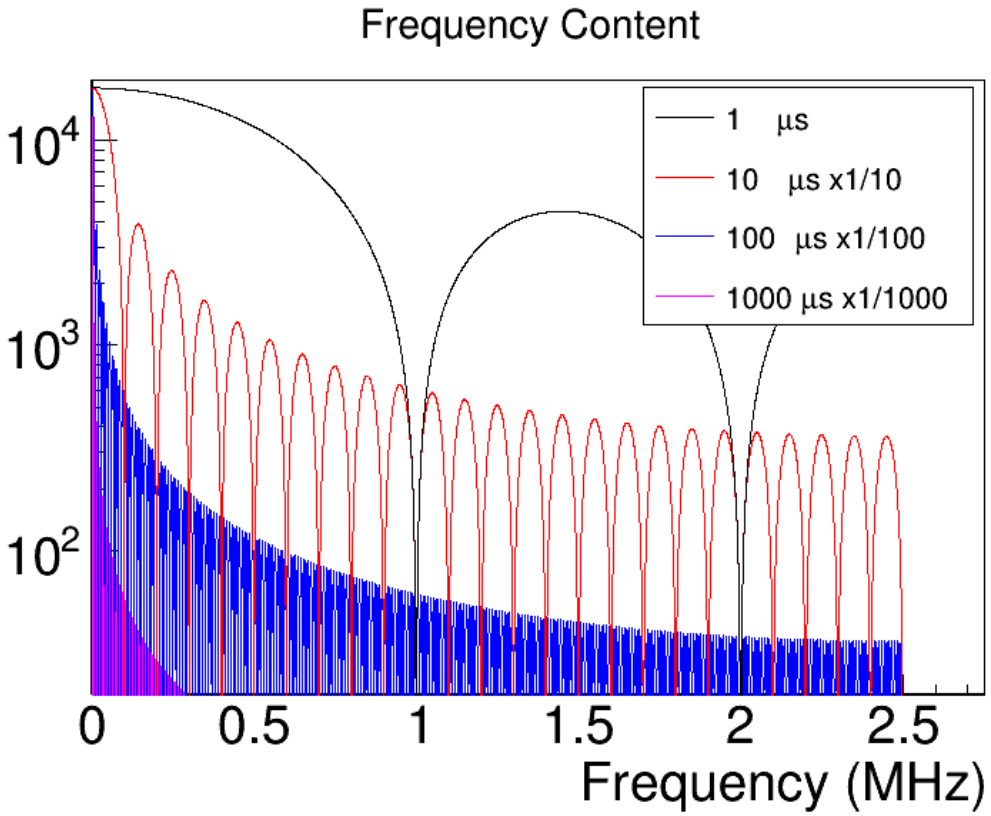




The induction signal is bipolar, thus, **suppression at low frequency**

Example of Some Typical Signals

- MIP signal is about 18k electrons for a 3 mm pitch, so we can look at the signal of 1us, 10 us long, 100 us long, 1000 us long



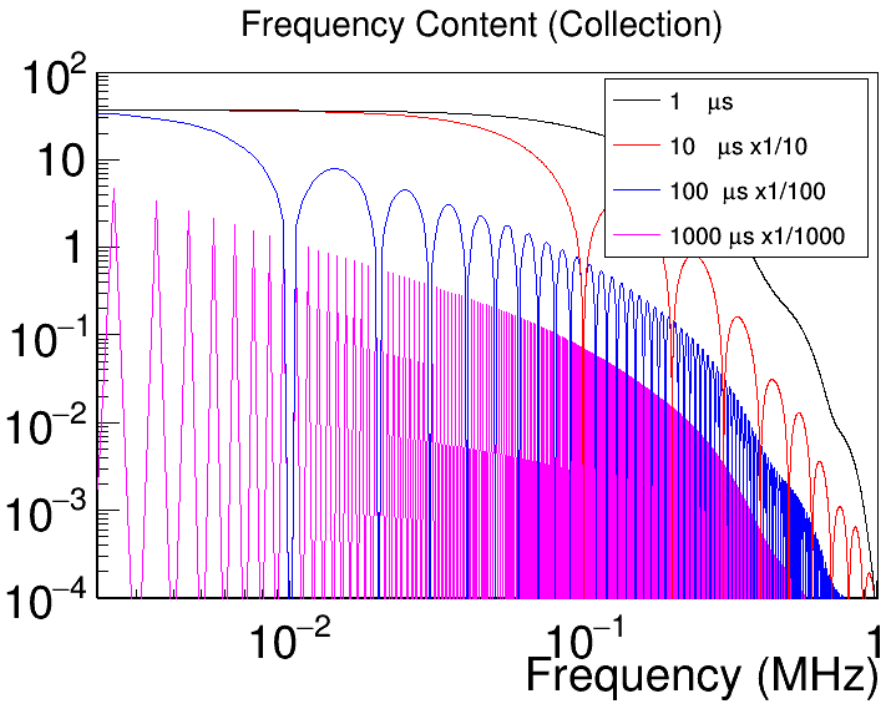
As signal becomes longer in the time domain, its frequency content is shifting towards the low frequency

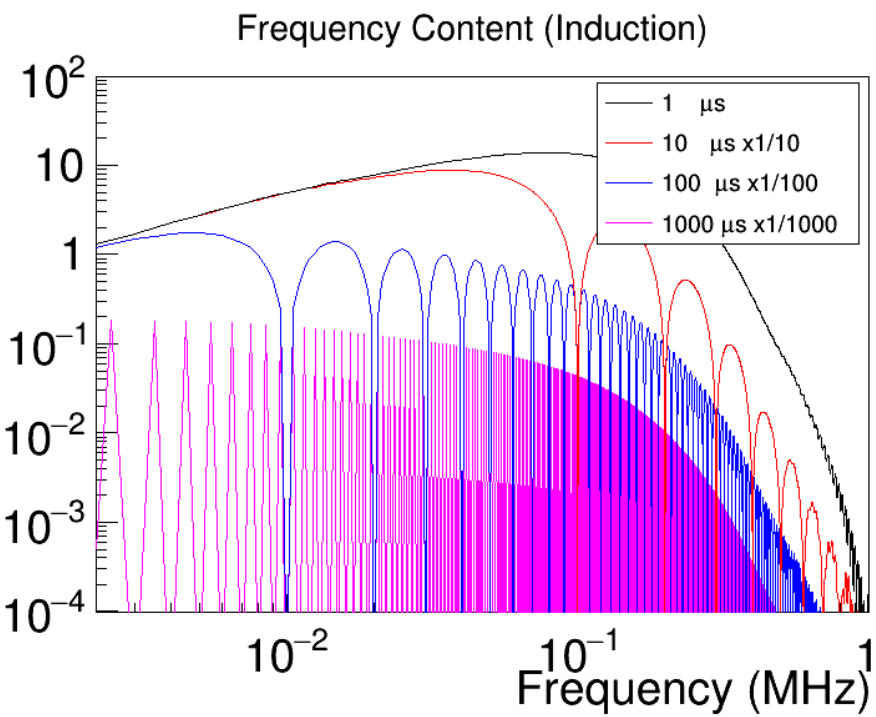
Low-frequency (high-pass) filter will remove long signal

Measured Signal

$$M(t_0) = \int S(t) R(t_0 - t)\, dt$$

$$M(\omega) = S(\omega) R(\omega)$$

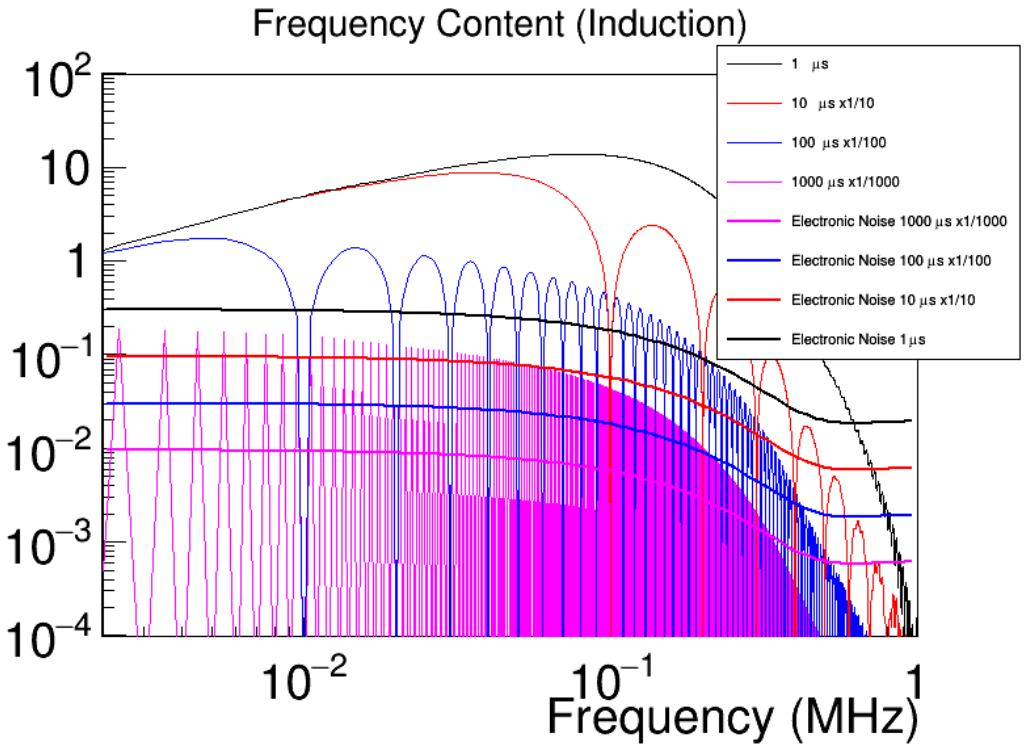




As expected, the induction plane signal has suppression at low-frequency. The longer signal is, the more reduction is

Why ROI is important for Induction Plane Signal?

- If the signal length is “T”, and the ROI is “2*T”



- Noise will also be larger due to larger window by ~sqrt(2)

ROI window	Minimum frequency
2 us	0.5 MHz
10 us	0.1 MHz
100 us	0.01 MHz
1000 us	0.001 MHz

- Even more difficult to identify the signal

- **Finding proper ROI is crucial for processing induction signal**
- **No such complication for the collection signal**

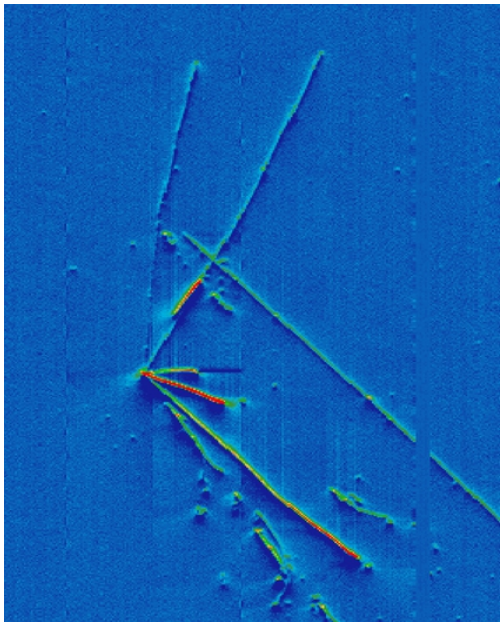
Semi-Summary

- Induction plane signal is complicated due to the bi-polar nature of the impulse response
  - Region of Interest (ROI) is important to reach best signal to noise ratio
  - Due to the existence of electronics noise, the longer the signal is, the less signal to noise ratio will be → difficult to find ROI robustly

- Four-plane can enhance finding ROIs

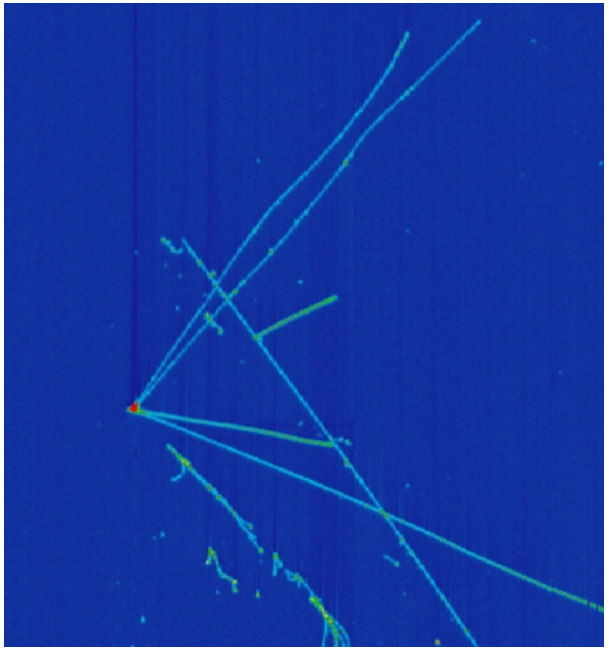
Four-plane ROI finder

- When ionization arrived at anode wire planes, signal are produced at each wire plane “simultaneously”
  - If we can find robust “ROIs” in three planes, then we can deduce ROI on the fourth plane
  - This is helpful in th[illegible] the signal is long on one-plane



U plane (Ind.)

V plane (Ind.)



W plane (Col.)

Discussion

- Robust ROIs depends on
  - Electronics noise level
  - Signal length in time

- Build long ROIs from robust ROIs can enhance the reach of induction plane signal → enhance the overall reconstruction efficiency
  - Can be compared to the dead channel case

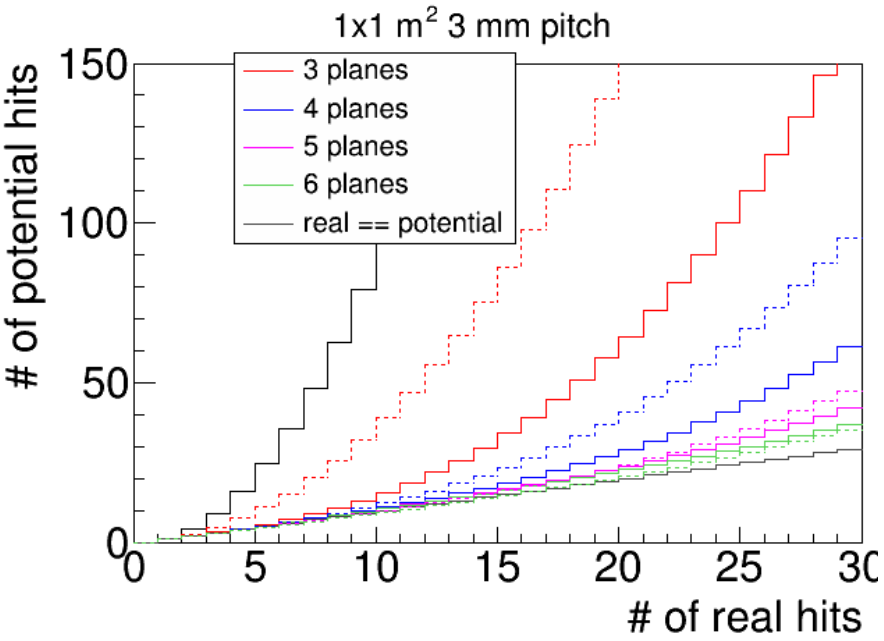
Summary

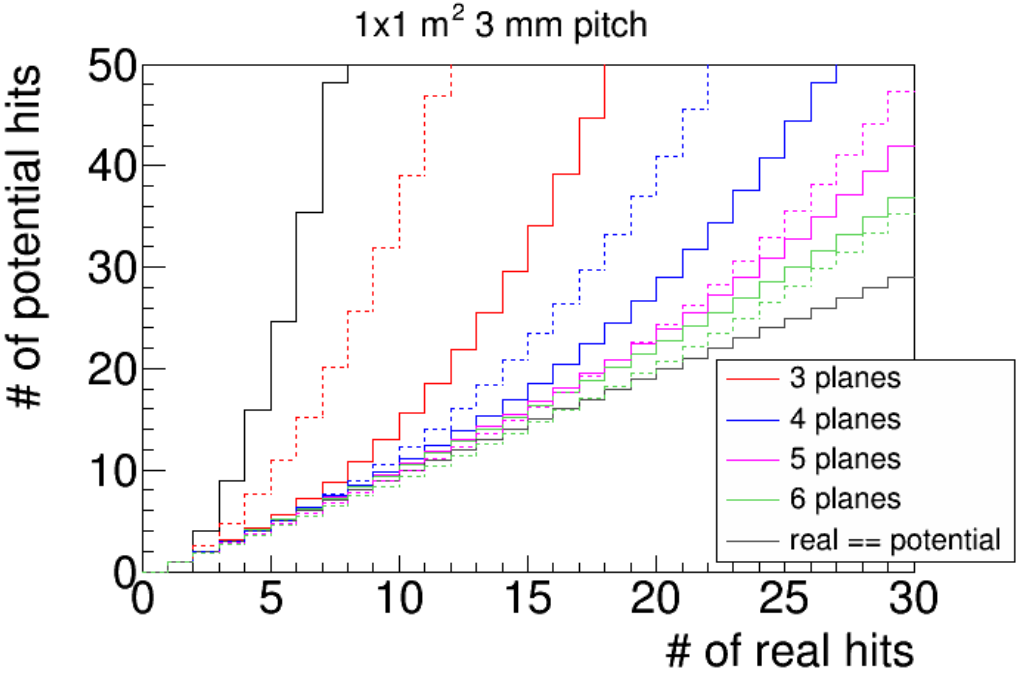
- Motivation of four wire plane for single-phase APA
  - Will reduce the amount of ambiguities, especially for busy event topologies (i.e. near vertex of the ve CC interaction)
  - Will be more robust against the dead channels (i.e. local and global)
  - Increase the acceptance for induction signal

Feasibility

- DUNE APA design has 4 planes (including grid) already
  - Grid plane is NOT needed from signal processing point of view
  - Grid plane (already at the correct bias) can be converted to an additional induction plane
  - With four plane, the choice of wire wrapping angle is less restricted

10% dead case


1x1 m^2 3 mm pitch
3 planes
4 planes
5 planes
6 planes
real == potential
# of potential hits
# of real hits
0
50
100
150
0
5
10
15
20
25
30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